

Meson exchange models for Meson production

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Abstract. The production of mesons in nucleon-nucleon collisions is reviewed from the viewpoint of the meson-exchange picture. In the first part various possible production mechanisms and their relative importance are discussed. In addition, general features of meson production are described.

In the second part special emphasis is put on pion production. Implications of chiral perturbation theory are discussed. Results based on a specific meson-exchange model for pion production in nucleon-nucleon collisions are presented. The model is utilized to calculate several spin-dependent observables of the reactions $pp \rightarrow pp\pi^0$ and $pp \rightarrow pn\pi^+$ such as spin-correlation parameters. This allows us to study the role of the Delta resonance at close to threshold energies.

The talk closes with a brief discussion of the production of ϕ mesons as an example for the production of heavier mesons. A strategy is outlined that allows to extract information on the structure of the nucleon from the reaction $NN \rightarrow NN\phi$.

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INTRODUCTION

With the advent of new accelerator technology measurements with very high accuracy became possible for meson production close to threshold [1]. This improvement opens the possibility for the investigation of a lot of interesting physics phenomena. It is the goal of this talk to highlight a few of those. This will be done using the meson exchange picture.

The largest part of the presentation will concentrate on pion production. As this is the first and most important inelasticity of the nucleon–nucleon system it shall deal as a guideline for models of the production of heavier mesons. In addition, for this channel there are not only analyzing powers but also double polarization data available. A study of this system will therefore allow us to get a feeling about what can be learned from meson production. In particular it will be demonstrated that using polarization observables will allow to study resonances that couple too weakly to significantly influence the unpolarized observables – in this example it will be the $\Delta(1235)$ far below the resonance position. However, the same kind of sensitivity should be found for resonances that have only a minor effect on the total cross section even at their resonance position. In addition: in the unpolarised observables almost all the effects of the Delta–isobar are driven by the $^1D_2 \rightarrow ^5S_2$ $NN \rightarrow N\Delta$ transition leading to p-wave π –production². Polarization observables allow to study less dominant transition amplitudes selectively and thus allow direct insight into the NN interaction.

There is one special feature to the production of pions: since they are pseudo Goldstone bosons of the spontaneous broken chiral symmetry, there is the possibility of studying pion production in nucleon–nucleon collisions with chiral perturbation theory. I will briefly compare the features of the meson exchange approach to those of chiral perturbation theory.

As an example for the production of heavier mesons I will continue with a short discussion of how one can use data on the production of vector mesons close to threshold to deduce information on the structure of the nucleon.

The presentation will close with a brief outlook.

GENERAL FEATURES OF MESON PRODUCTION IN NUCLEON–NUCLEON COLLISIONS

To produce a meson in nucleon nucleon collisions the initial kinetic energy needs to be large enough to put the outgoing meson on its mass shell. The initial center of mass momentum required to produce a meson of mass m turns out to be at

²) This transition is prohibited for the $pp \rightarrow pp\pi^0$ reaction and this is why the Delta is less important for the neutral pion production (see below).

least $p = \sqrt{Mm + \frac{m^2}{4}}$, where M denotes the nucleon mass. If the kinematics is chosen close to the threshold the outgoing particles are (almost) at rest. Thus, large characteristic for the meson production close to threshold. This leads to a big momentum mismatch between the final wave-function and the initial one leading to a suppression of the direct production mechanisms (c.f. Fig. 1a and d for pion production). Therefore short range processes dominate the production (c.f. Fig. 1b³ and c). Note, however, once one moves away from threshold the range of allowed final momenta increases. Thus moderate momentum transfers become more and more likely and higher partial waves come into play. Thus, one should expect very different production mechanisms to be dominant as a function of the excess energy. The range of energies just described can be identified with the range of $0 \leq \eta \leq 1$, where η denotes the maximum meson momentum in units of the meson mass. Therefore, in this presentation we will mainly concentrate on this regime.

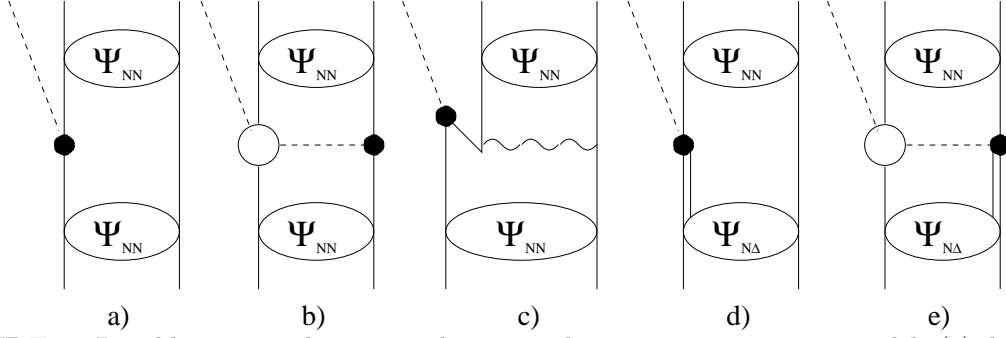


FIGURE 1. Possible pion production mechanisms taken into account in our model: (a) direct production; (b) pion rescattering; (c) contributions from pair diagrams; (d) and (e) production involving the excitation of the $\Delta(1232)$ resonance. Note that diagrams where the Δ is excited after pion emission are also included.

The goal of the meson exchange picture is to find a description of meson production that is both transparent enough to be able to identify the relevant physics of the process and still contains all the relevant dynamics. In this context it is important to understand the special role that the nucleon–nucleon system plays in the initial as well as the final state.

As early as 1952 Watson pointed out the significance that the final state nucleon–nucleon interaction should play in meson production processes close to threshold [2]. To see this let us consider meson absorption on a two nucleon system, which is related to meson production through detailed balance. The cross section is a measure of the volume in which all three particles must be simultaneously in order to make the absorption process possible. However, since the elastic scattering cross section for the two nucleons is very much larger than the production cross section and the NN interaction close to threshold is strongly attractive, a two step process is favored in which first the two nucleons approach at close range – driven

³⁾ For large space like momentum transfers, the πN T-matrix enters far off-shell and thus also the pion exchange contribution should be considered as a short range process.

by the NN interaction – before the meson comes into play. Therefore the energy dependence of the absorption (production) matrix element should be given by the energy dependence of the initial (final) nucleon–nucleon interaction. If we neglect the effect of the meson–nucleon interaction and use the effective range expansion for the nucleon–nucleon interaction the energy dependence of the total production cross-section close to threshold should be given by

$$\sigma_{NN \rightarrow NNx}(\eta) \propto \int_0^{m_x \eta} dq' q'^2 \frac{p'}{1 + a(a + r_o)p'^2} , \quad (1)$$

where $a(r_o)$ denotes the nucleon–nucleon scattering length (effective range) in the relevant channel and p' and q' denote the relative momenta of the two nucleons and of the meson with respect to the two nucleons respectively. It was shown in ref. [3] that the inclusion of the Coulomb effect is important, if for a two proton final state. The inclusion of the Coulomb effect in eq. 1 is straightforward [4]. It turns out that the energy dependence of the total cross section that follows from eq. 1 is in nice agreement with almost all experimental evidence on meson production near threshold [1]. The only exception is the production of η mesons, since the ηN interaction is too strong to be neglected (see also ref. [5]).

The above argument shows that it is important to include the final state interactions of the produced particles in order to describe the energy dependence of the total cross sections correctly. Reversing this statement indicates, that it is possible to relate the energy dependence of the near threshold production cross sections to low energy parameters of the dominant interactions. Examples for this are given in ref. [6] for the ΛN interaction and in refs. [7,8] for the ηN interaction.

Care should be taken, however, when trying to deduce a general formula like eq. 1 not only to describe the energy dependence but also to set the normalization of the effect of the FSI independent of the production operator. This statement is illustrated by different groups using different prescriptions for the normalization of the FSI factor that differ by more than an order of magnitude, although both use the meson exchange picture to calculate the production operator (c.f. e.g. refs. [5] and [9]). Based on quite general arguments one can show, that there is no model independent way to fix the normalization introduced by the FSI factor [11]⁴.

A similar reasoning that lead to the successful description of the energy dependence of the total cross section leads to an expression that describes the effect of the initial state interaction [11]: In order to allow the production to proceed, the two incoming nucleons have to come very close to each other. There are two mechanisms that potentially prevent this, namely elastic and inelastic scattering. If we focus on the meson exchange picture, it can be argued that the principal value integral that introduced the scheme dependence for the FSI is actually small for

⁴) The method applied in refs. [5,9] was also criticized in ref. [10] from a different point of view, namely, that the inclusion of the FSI through using a plane wave that is modified in strength according to the on-shell scattering data misses the short range correlations introduced by the FSI and thus leads to wrong relative weights of the individual contributions.

high energies⁵. Based on this observation one can derive a rough estimate for a suppression factor induced by the ISI (for a discussion of the range of applicability see [11])

$$\lambda = \frac{1}{4}(1 + \eta_L)^2 - \eta_L \sin^2(\delta_L) , \quad (2)$$

where η_L and δ_L denote the inelasticity and the phaseshifts of the partial wave in the initial state relevant for the meson production under consideration. Using the numbers given by the SAID database [12] we find for the η and η' production values of $\lambda = \frac{1}{5}$ and $\lambda = \frac{1}{3}$ respectively. Note, that the former number covers the bulk effect of the initial state interaction calculated within a meson exchange model [13]. Thus, the ISI leads to a non negligible suppression of the total cross section and should be taken into account.

PION PRODUCTION AND THE ROLE OF THE Δ CLOSE TO THRESHOLD

As this is meant to be an overview presentation, this section starts with a brief history of the field.

Essentially all recent theoretical investigations on pion production near threshold are based on the model proposed by Koltun and Reitan in 1966 [14]. In this model two production mechanisms are considered: direct production (Fig. 1a), and pion rescattering (Fig. 1b) – the latter, however, in on-shell approximation, where the πN -T-matrix is replaced by the scattering length. It is important to note that – as a consequence of chiral symmetry – the isoscalar scattering length⁶ almost vanishes. This model was utilized by Miller and Sauer in 1991 [3] to analyze the first set of high precision data of the reaction $pp \rightarrow pp\pi^0$ near threshold that became available from IUCF [15]. It turned out that such a model grossly underestimates the empirical cross section [3]. Note, that isovector rescattering is prohibited in this reaction channel.

In 1992 Niskanen extended this model by including the Δ (1235) isobar (cf. Fig. 1d and e) [16]. Furthermore, he allowed for an energy dependence in the s-wave rescattering term, however, still keeping the on-shell approximation [17]. These improvements roughly doubled the predicted $pp \rightarrow pp\pi^0$ cross section, but Niskanen's results still underestimate the IUCF data by a factor of 3.6.

Another new production mechanism was introduced by Lee and Riska in 1993 [18]. These authors considered effects from meson-exchange currents due to the exchange of heavy mesons that excite a nucleon-antinucleon pair, as shown in Fig. 1c. It was found that the resulting contributions (in particular the one of the

⁵) Remember: there is no such thing as a model independent splitting of the NN interaction and the production operator.

⁶) The πN -T-matrix can be written as a linear combination of an isoscalar and an isovector part.

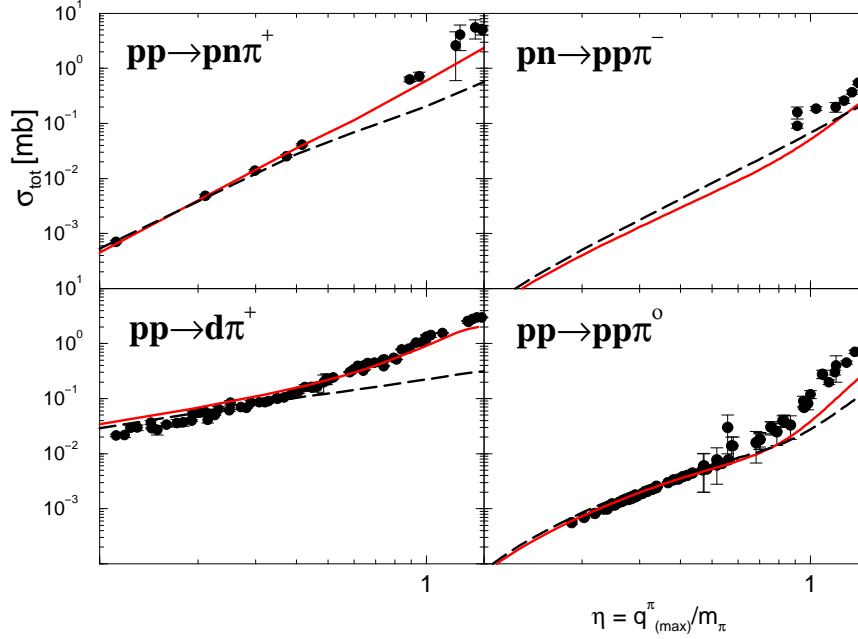


FIGURE 2. Total cross sections for the different pion production channels. The solid line represents the result of the full model of ref. [32], whereas for the dashed line the contributions involving the Δ where omitted. For a compilation of the experimental data see ref. [1].

ω meson) enhance the pion production cross section by a factor of 3-5 [18,19] and thus eliminate most of the under prediction found in earlier investigations.

However, in 1995 Hernández and Oset presented an alternative explanation for the missing strength in the π^0 production close to threshold [20]. These authors took into account the off-shell properties of the πN amplitude in the evaluation of the rescattering diagram. It turned out, that this enhances the rescattering contribution sufficiently to describe the empirical $pp \rightarrow pp\pi^0$ cross-section without the inclusion of additional short ranged diagrams. In the same year our group performed a calculation using a microscopic model for the πN T-matrix [21]. Although the effect of the rescattering was not as large as reported in [20] its enhancement due to the off-shell part of the T-matrix was quite significant.

Since the pion is the Goldstone Boson of the chiral symmetry one might hope that the framework of chiral perturbation theory allows more insight into this fundamental reaction. In the literature there is a series of papers available, that use tree level chiral perturbation theory to calculate the cross sections close to threshold for both neutral pion production [22–25] and charged pion production [26,27]. In addition there are two calculations available that calculate the π^0 production to one loop order [28,29] – these, however, use heavy baryon chiral perturbation theory which is inappropriate in the present kinematics [5]. The advantage of chiral perturbation theory compared to the meson exchange picture is, that one has an organizing principle at hand. Although the expansion parameter is quite large

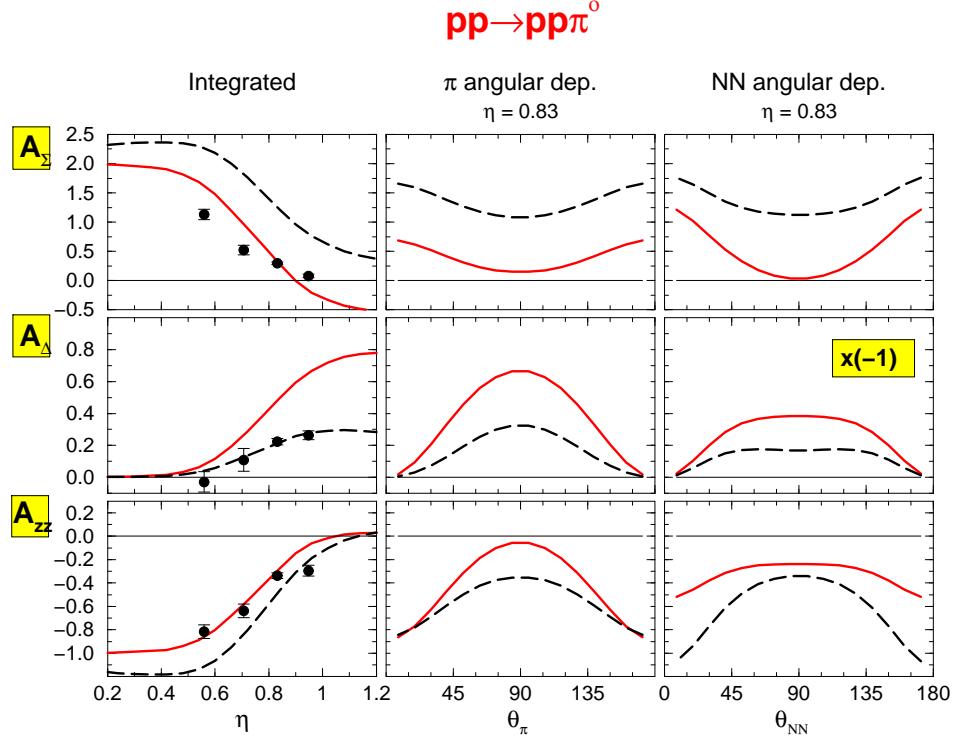


FIGURE 3. Spin correlation parameters for the reaction $pp \rightarrow pp\pi^0$, where $A_\Sigma = A_{xx} + A_{yy}$ and $A_\Delta = A_{xx} - A_{yy}$. Curves are the same as in Fig. 2. The experimental data are taken from Refs. [35,36].

in case of the $NN \rightarrow NN\pi$ reactions, namely $Q = \sqrt{m/M} \simeq \frac{1}{3}$ [23], it is very illuminating to study the lowest order contributions and to compare those to the diagrams depicted in Fig. 1.

Based on the counting rules employed in ref. [23] the lowest order contributions to pion production close to threshold ($O(Q)$) are for the neutral pion production the direct production from the nucleon as well as from the delta (Fig. 1a and d), whereas in case of the charged pion production at the same order there appears a rescattering diagram (Fig. 1b) involving the isovector πN interaction in addition [26,27]. As it was argued above, the large momentum transfer characteristic of meson production close to threshold leads to a suppression of the direct production mechanisms in favor of rescattering and short range processes. Therefore, one expects the production of charged pions to be under better control than the one of neutral pions – that is indeed what we experience: the lowest order calculation for the π^+ production deviates from the data by a factor of 2 [26,27] whereas the one for π^0 production deviates by more than an order of magnitude (the latter occurs because the individual contributions are small and there is a cancelation between the Δ contribution (Fig. 1d) and the nucleonic one (Fig. 1a) [23]).

At the next order ($O(Q^3)$) in both channels loops enter⁷ as well as contact interactions (the effective field theory analog of the short range contributions of the meson exchange picture) and rescattering diagrams. The strength of the contact interactions is not constrained by chiral symmetry. Therefore the authors of refs. [23,24,27] tried to estimate their strength by means of resonance saturation: the contact interactions were identified with short ranged diagrams (Fig. 1c) that were evaluated using parameters from realistic NN potentials. However, it is not clear a priori, that this procedure makes sense for the contact interactions. The parameters relevant for the rescattering can be related to πN scattering [30].

Taking all this together it should not come as a surprise that the s-wave pion production is not well under control theoretically. As it was argued before the typical momentum transfers decrease as we move away from the production threshold and it is the large momentum transfer that causes all the trouble. A more appropriate approach to pion production close to threshold thus seems to be to first understand the higher partial waves and then to move down in energy. This procedure should allow one to study the onset of new physics in a more controlled way what highlights the importance of looking at higher partial waves. It should be noted that one expects the chiral expansion to work better, when the pions are produced in higher partial waves [31]. Therefore in what follows we will concentrate on polarization observables for here the higher partial waves show up most clearly.

To be more concrete in what follows we will compare the results of a particular meson exchange model [32] to the data. In the literature there is only one additional model that considers all the different pion production channels as well as higher partial waves, namely the one by the Osaka group. This model was described in a different presentation in some detail [33], and thus we will not discuss it here.

In the Jülich model [32] all standard pion-production mechanisms (direct production (Fig. 1a), pion rescattering (Fig. 1b), contributions from pair diagrams (Fig. 1c) are considered – the latter, however, are treated as a parametrisation of all the missing short range mechanisms. In addition, production mechanisms involving the excitation of the $\Delta(1232)$ resonance (cf. Fig. 1d,e) are taken into account explicitly. All NN partial waves up to orbital angular momenta $L_{NN} = 2$, and all states with relative orbital angular momentum $l \leq 2$ between the NN system and the pion are considered in the final state. Furthermore all πN partial waves up to orbital angular momenta $L_{\pi N} = 1$ are included in calculating the rescattering diagrams in Fig. 1b,e. Thus, our model includes not only s-wave pion rescattering but also contributions from non resonant p-wave rescattering. For details about the model we refer the reader to ref. [32].

Results of this model for total cross sections for the reactions channels $pp \rightarrow pp\pi^0$, $pp \rightarrow pn\pi^+$, $pn \rightarrow pp\pi^-$, and $pp \rightarrow d\pi^+$ are displayed in Fig. 2. Results for analyzing powers were presented in Refs. [32,34]. It was found that the model yields a very good overall description of the data from the threshold up to the Δ resonance region. In fact, a nice quantitative agreement with basically all experimental infor-

⁷⁾ This is true only when using the counting scheme of ref. [23].

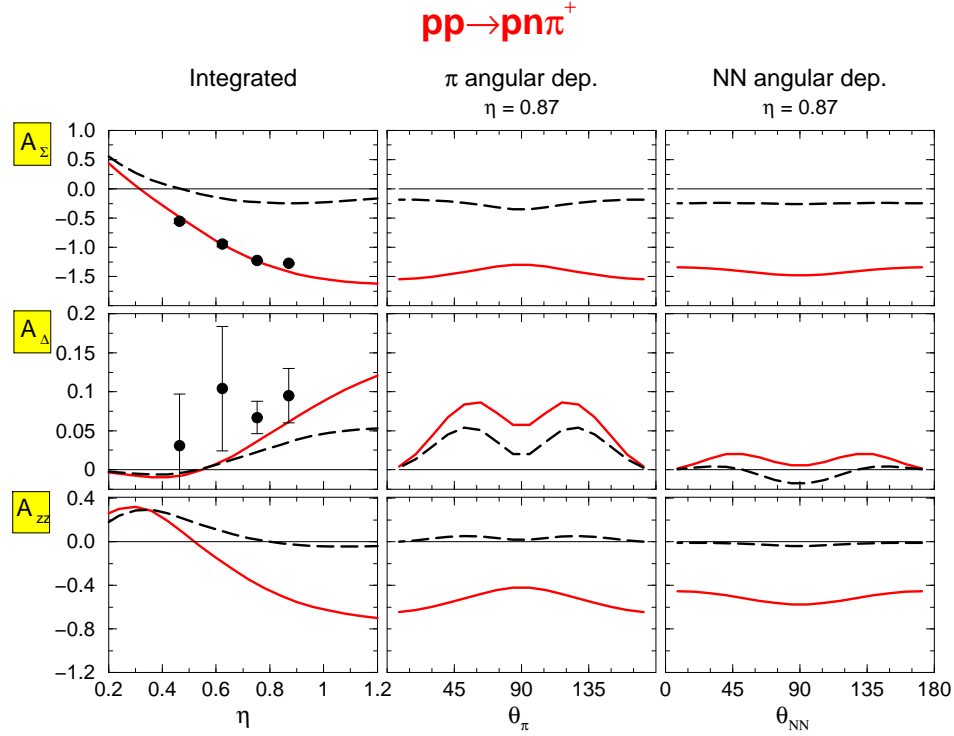


FIGURE 4. Spin correlation parameters for the reaction $pp \rightarrow pn\pi^+$. Same description of the curves as in Fig. 2. The experimental data are taken from Ref. [37].

mation (then available) was observed over a wide energy range. Thus, this model is very well suited as a starting point for a detailed analysis of the forthcoming spin-dependent observables of the reaction $NN \rightarrow NN\pi$.

Looking at the results for the total cross sections one observes that the role of the Δ is very different in the different production channels: it dominates the π^+ production at values of $\eta > 1$ but it appears much less relevant anywhere else. As we will see in the following, this is no longer true for polarization observables. Here the Δ turns out to be very important in all production channels in the whole energy range if one wants to describe the spin observables as well. This clearly demonstrates the power of polarization observables to investigate resonances even if their effect is too weak to show up in unpolarized observables!

Predictions for the spin correlation coefficient combinations $A_\Sigma = A_{xx} + A_{yy}$, $A_\Delta = A_{xx} - A_{yy}$ and A_{zz} are shown in Figs. 3 (for $pp \rightarrow pp\pi^0$) and 4 (for $pp \rightarrow pn\pi^+$). The polar integrals of these observables are displayed in the left panels as a function of η . The other two panels contain the results for the different observables as a function of the pion angle (middle panel) and of the angle between the nucleons (right panel). Data for these observables are currently being analyzed [38].

Again the solid line shows the results for the full model, whereas the dashed line are the results when all contributions involving the Δ are omitted. As can be seen clearly from the figure, the inclusion of the isobar is essential for all the polarization

observables displayed even at energies as low as $\eta = 0.4$!

Our model is not able to describe $A_{xx} - A_{yy}$ in the reaction $pp \rightarrow pp\pi^0$ (c.f. Fig. 3). The numerator of this observable is sensitive to Pp partial waves only [39] (Here capital letters denote the NN relative momentum whereas the small letters denote the pion angular momentum with respect to the NN system). Does figure 3 therefore tell us that all but the Pp piece is correctly reproduced by our model⁸? The answer is no. There is a possible other explanation, namely that it is not the numerator of $A_{xx} - A_{yy}$ but the denominator that causes the deviation. Note, that our model underestimates the total cross section for π^0 production by a factor of 2 at energies of $\eta = 1$ (c.f. Fig. 2).

As it was pointed out in ref. [36], it is possible to relate the integrated double polarization observables to the spin cross sections (the cross sections one gets for a given initial spin state). At moderate energies these should be dominated by the lowest partial waves. A possible way to get better insights could therefore be to look at the spin cross sections directly. However, in their determination the total cross section enters besides the double polarization observables. The former, however, is badly known at energies around $\eta = 1$. Better data is needed to accurately constrain the spin cross sections in the energy region of interest. Fortunately those data will soon be available [40].

VECTOR MESON PRODUCTION

In this section we will briefly discuss, how the investigation of vector meson production in nucleon–nucleon collisions can improve our knowledge on the structure of the nucleon. In particular we will outline a method on how to deduce information on the $NN\phi$ coupling constant from data on differential cross sections recently measured by the DISTO collaboration [41].

This information can be regarded as complementary to recent experiments on $\bar{p}p$ annihilation at rest, where the unexpectedly large cross section ratios $\sigma_{\bar{p}p \rightarrow \phi X} / \sigma_{\bar{p}p \rightarrow \omega X}$ (cf. Ref. [42] for a compilation of data) were interpreted by some authors as a clear signal for an intrinsic $\bar{s}s$ component in the nucleon [42]. However, in an alternative approach based on two-step processes these data were explained without introducing any strangeness in the nucleon and any explicit violation of the OZI rule [43].

In this context ϕ production in nucleon-nucleon collisions is of specific interest. Here one does not expect any significant contributions from competing OZI-allowed two-step mechanisms. Therefore cross section ratios $\sigma_{pp \rightarrow pp\phi} / \sigma_{pp \rightarrow pp\omega}$ should provide a clear indication for a possible OZI violation and the amount of hidden strangeness in the nucleon – note, that data recently presented by the DISTO collaboration indicate that this ratio is about 8 times larger than the OZI estimate [41]. Based on a model calculation in this section it will be investigated, if the

⁸) This was given as a possible explanation of this deviation in ref. [32].

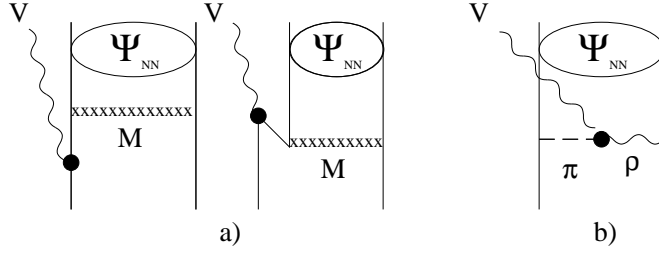


FIGURE 5. ϕ and ω -meson production currents included in the present study: (a) nucleonic current (the diagrams with the production after the meson exchange are also included), (b) meson exchange current. $v = \omega, \phi$ and $M = \pi, \eta, \rho, \omega, \sigma, a_0$.

observed enhancement over the OZI estimate in the cross section implies a $g_{NN\phi}$ that is likewise enhanced and therefore at variance with the OZI rule. It should be emphasized that the investigation is by far not as ambitious as the study of pion production, for the individual ingredients are much less known. The major goal of this study is to extract constraints on $g_{NN\phi}$ from the ω to ϕ ratio.

As before we also describe the $pp \rightarrow pp\phi$ reaction within a relativistic meson-exchange model, where the transition amplitude is calculated in DWBA in order to take the NN final state interaction into account. (See Ref. [44] for the details of the formalism.) For the NN interaction we employ the model Bonn B [45]. The effect of the ISI is accounted for via an appropriate adjustment of the (phenomenological) form factors at the hadronic vertices.

In a previous study of the reaction $pp \rightarrow pp\omega$ [44] it was found that the dominant production mechanisms are the nucleonic and $\omega\rho\pi$ mesonic currents, as depicted in Fig. 5. Note, that in contrast to the pion production here we take the Born diagram for the $\pi N \rightarrow \omega N$ T-matrix multiplied with a phenomenological form-factor and not a microscopic T-matrix. However, this is not a serious drawback for the current investigation, since this formfactor is anyhow adjusted to the data. The reason why it is still possible to extract important information from the vector meson production is, that the angular distribution of the produced vector meson provides a unique and clear signature of the magnitude of these currents, thus allowing one to disentangle these two reaction mechanisms. Therefore, it is possible to fix uniquely the magnitudes of the nucleonic and the meson-exchange current by analyzing the angular distribution of the ϕ meson measured by the DISTO collaboration [41]. Furthermore, since the $NN\phi$ coupling constant enters only in the nucleonic current it is possible to extract its value from such an analysis. It is determined by the requirement of getting the proper contribution of the nucleonic current needed to reproduce the angular distributions.

The parameters of the model (coupling constants, cutoff masses of the vertex form factors) are mostly taken over from the employed NN model. The $\phi\rho\pi$ coupling constant is obtained from the measured decay width of $\phi \rightarrow \rho + \pi$. However, besides the $g_{NN\phi}$ that we want to extract from the analysis, there are still some

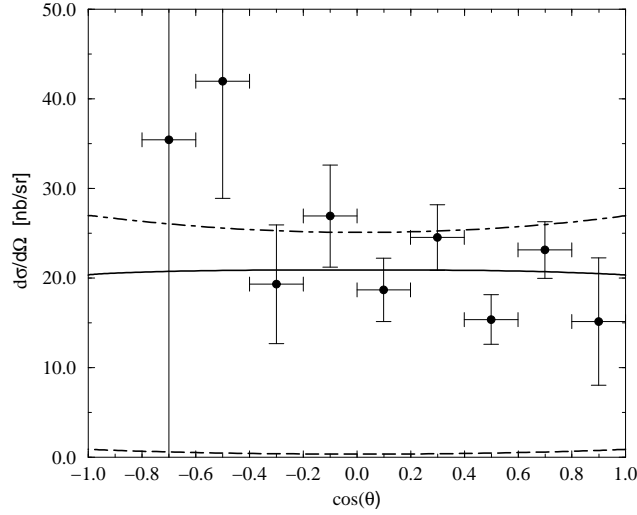


FIGURE 6. Angular distribution for the reaction $pp \rightarrow pp\phi$ at an incident energy of $T_{lab} = 2.85$ GeV. The dashed-dotted curve corresponds to the mesonic current contribution, the dashed curve to the nucleonic current contribution. The solid curve is the total contribution. The experimental data are from Ref. [41].

more free parameters: The cutoff mass of the $\phi\rho\pi$ vertex form factor of the meson-exchange current, and the form factor and tensor- to vector coupling constant ratio $\kappa_\phi \equiv f_{NN\phi}/g_{NN\phi}$ of the nucleonic current. It is possible to fix most of them by performing a combined analysis of the ω and ϕ data as well as other sources (cf. Ref. [46] for details). The remaining unknown is the tensor coupling. Here we assume that $\kappa_\phi = \kappa_\omega$, as also suggested by SU(3) symmetry, and $-0.5 \leq \kappa_\omega \leq 0.5$.

After the above considerations, we are now prepared to apply the model to the reactions $pp \rightarrow pp\omega$ and $pp \rightarrow pp\phi$. The angular distribution for ϕ -meson production measured at $T_{lab} = 2.85$ GeV is shown in Fig. 6. We observe that the angular distribution is fairly flat. Recalling the results we obtained for ω production [44] this tells us that ϕ -meson production should be almost entirely due to the $\phi\rho\pi$ meson-exchange current. Only a very small contribution of the nucleonic current is required if the angular distribution drops at forward and backward angles, as indicated by the data⁹.

Details about our strategy for fixing the various parameters and information about the data used in the analysis can be found in Ref. [46]. We get a set of values which range from

$$-1.4 \leq g_{NN\phi}^{model} \leq -0.163. \quad (3)$$

Note, that the spread is not an estimate of the theoretical uncertainty of the model but reflects the remaining uncertainty within the model – this will be reduced

⁹⁾ Note, that since there are identical particles in the initial state the angular distribution has to be symmetric around 90 degrees.

sufficiently as soon as more experimental information is available. Nevertheless, it is encouraging to see that the extracted values all lie within fairly narrow bounds. This clearly indicates to us that the dependence on the model parameters is not very strong, and that the magnitude of $g_{NN\phi}$ is primarily determined by the experimental information used.

The values of $g_{NN\phi}$ obtained may be compared with those resulting from SU(3) flavor symmetry considerations and imposition of the OZI rule,

$$g_{NN\phi}^{OZI} = -3g_{NN\rho} \sin(\alpha_v) \cong -(0.60 \pm 0.15) ,$$

where the factor $\sin(\alpha_v)$ is due to the deviation from the ideal $\omega - \phi$ mixing. The numerical value is obtained using the values of $g_{NN\rho} = 2.63 - 3.36$ [47] and $\alpha_v \cong 3.8^\circ$. Comparing this value with the ones extracted from our model analysis, we conclude that the preliminary data presently available can be described with using a $NN\phi$ coupling constant that is compatible with the OZI rule. This clearly indicates that a dynamical model is needed for drawing any conclusion about the validity of the OZI rule.

SUMMARY AND OUTLOOK

The main points of the presentation can be summarized as

- it is important to take into account the nucleon–nucleon interaction in the final as well as in the initial state to get a quantitative understanding of meson production close to threshold,
- the interesting energy regime for meson production is $0 \leq \eta \leq 1$, for this regime includes both large and moderate momentum transfers,
- polarization observables allow to detect resonances, even if their effect is too small to show up in the total cross section. Note, that this statement is true only if there is a spin dependent coupling of the resonance to the produced meson.

It should be made clear that theory lacks far behind experiment. However, the large amount of experimental information that is going to be available within the next years will help us to get a better understanding of meson production reactions and will therefore guide us to better models and insights into the phenomenology of the nucleon–nucleon interaction.

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REFERENCES

1. For a short review and references to experimental as well as theoretical papers see, e.g., H. Machner and J. Haidenbauer, *J. Phys. G* **25**, R231 (1999).
2. K. Watson, *Phys. Rev.* **88**, 1163 (1952).
3. G. A. Miller and P. Sauer, *Phys. Rev.* **C44**, 1725 (1991).
4. H.O. Meyer et al., *Nucl. Phys. A* **539**, 633 (1992).
5. V. Bernard, N. Kaiser and Ulf-G. Meißner, *Eur. Phys. J A4*(1999) 259 and N. Kaiser, these proceedings.
6. J.T. Balewski et al., *Eur.Phys.J.* **A2**, 99 (1998).
7. A.M. Green, J.A. Niskanen and S. Wycech, *Phys. Rev. C* **54**.
8. V.Y. Grishina et al., **nucl-th/9905049**.
9. A. Sibirtsev and W. Cassing, *Eur. Phys. J.* **A2**, 333 (1998)
10. J. A. Niskanen, *Phys.Lett. B***456**, 107 (1999).
11. C. Hanhart and K.Nakayama, *Phys. Lett. B* **454**, 176 (1999).
12. extracted from the VIRGINIA TECH PARTIAL-WAVE ANALYSES ON-LINE (http://clsaid.phys.vt.edu/CAPS/said_branch.html)
13. M. Batinic, A. Svarc and T.-S.H. Lee, *Phys.Scripta* **56**, 321 (1997).
14. D. Koltun and A. Reitan, *Phys. Rev.* **141**, 1413 (1966).
15. H.O. Meyer et al., *Phys. Rev. Lett.* **65**, 2846 (1990);
16. J. Niskanen, *Phys. Lett.* **B289**, 227 (1992).
17. J. Niskanen, *Phys. Rev.* **C49**, 1285 (1994).
18. T.-S. Lee and D. Riska, *Phys. Rev. Lett.* **70**, 2237 (1993).
19. C.J. Horowitz, H.O. Meyer and D.K. Griegel, *Phys. Rev.* **C49**, 1337 (1994).
20. E. Hernández and E. Oset, *Phys. Lett.* **B350**, 158 (1995).
21. C. Hanhart et al., *Phys. Lett.* **B358**, 21 (1995).
22. T.Y. Park et al., *Phys. Rev.* **C53**, 1519 (1996)
23. T.D. Cohen et al., *Phys. Rev. C* **53**, 2661 (1996).
24. U. van Kolck, G.A. Miller and D.O. Riska, *Phys. Lett.* **B388** (1996) 679.
25. T. Sato, T.-S.H. Lee, F. Myhrer and K. Kubodera, *Phys. Rev. C* **56**, 1246 (1997).
26. C. Hanhart et al., *Phys. Lett. B* **424**, 8 (1998).
27. C. da Rocha, G. A. Miller, and U. van Kolck, **nucl-th/9904031**
28. By E. Gedalin, A. Moalem, L. Razdolskaya, *Phys. Rev. C* **60**, 31 (1999).
29. V. Dmitrasinovic, K. Kubodera, F. Myhrer and T. Sato, **nucl-th/9902048**
30. V. Bernard, N. Kaiser and Ulf-G. Meißner, *Nucl. Phys. B* **457**, 147 (1995) and *Nucl. Phys. A* **615**, 483 (1997).
31. U. van Kolck, private communication.
32. C. Hanhart, J. Haidenbauer, O. Krehl, and J. Speth, *Phys. Lett. B* **444**, 25 (1998).
33. Y. Maeda et al., *πN Newsletter* **13**, 326 (1997) and K. Tamura, these proceedings.
34. C. Hanhart, J. Haidenbauer, and J. Speth, *Acta Phys. Pol. B* **29**, 3047 (1998).
35. H.O. Meyer et al., *Phys. Rev. Lett.* **81**, 3096 (1998).
36. H.O. Meyer et al., **nucl-ex/9907017**.
37. K. Swapn et al., **nucl-ex/9907016**.
38. J. Balewski, these proceedings.
39. H.O. Meyer, in *Baryons '98. Proceedings of the 8th International Conference on the*

Structure of Baryons, edited by D.W. Menze and B.Ch. Metsch (World Scientific, Singapore 1999), pp. 493.

- 40. J. Zlomaczuk, these proceedings.
- 41. F. Balestra et al., Phys.Rev.Lett.81(1998)4572
- 42. J. Ellis et al., *Phys. Lett. B* **353**, 319 (1995).
- 43. See, e.g., V.E. Markushin and M.P. Locher, *Eur. Phys. J. A* **1**, 91 (1998).
- 44. K. Nakayama et al., *Phys. Rev. C* **57**, 1580 (1998).
- 45. R. Machleidt, *Adv. Nucl. Phys.* **19**, 189 (1989).
- 46. K. Nakayama et al., Phys. Rev. **C60** (1999) 055209.
- 47. G. Höhler and E. Pietarinen, *Nucl. Phys. B* **95**, 210 (1975).
- 48. Collaboration CRN Strasbourg, IPN Orsay, LNS Saclay, in *Nouvelles de Saturne no. 19*, p.51 (Saclay 1995)